Abstract. The Cousins R and I images of $\sim 13' \times 13'$ region in the disk of M31 galaxy are taken on 141 nights during November 1998 to January 2002. A photometry on the extracted stars was done to search for variables. Of the 27 Cepheid variables present in the region, thirteen are reported for the first time while in the remaining stars, we confirm the Cepheid variability. Of the 13 discovered Cepheids, variability itself in 2 stars is being reported for the first time. The extensive photometry of these Cepheids enabled us to determine precise phase and amplitude of pulsation which ranges from 0.07 to 0.48 mag in R band. The period of variability ranges from $\sim$7.5 to 56 days, though 75% of them have period less than 18 days. The period-luminosity diagram is used to derive a distance modulus of 24.47$\pm$0.11 mag for M31 galaxy. We also report variability in 333 other stars, of them 301 are identified for the first time. Amongst them, 115 stars appear to be long period variables, 2 nova-like, 2 eclipsing binaries and remaining 214 are irregular variables. More observations are needed to determine their precise period, mean magnitude and other characteristics.

Key words: Cepheids – variable stars – M31 Galaxy – photometry

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Discovery of Variables including 13 Cepheids in M31 Galaxy

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1. Introduction

In recent years, the Andromeda galaxy (M31) has been a target of search for gravitational microlensing events (Crotts & Tomaney 1996, Ansari et al. 1997). To detect lensing events, continuous observations are needed for a long duration though for a short period of time each night. Such observations are, therefore, very useful to search for variable stars (e.g. Cepheids, Miras) also. The catalogues of variable stars compiled from such a monitoring programme are generally complete within the flux limitation, because of the continuous observation of the same field over a long period. Various groups (e.g. MACHO, EROS and OGLE) dedicated to search for microlensing events in the Galactic Bulge and Magellanic Clouds have already identified a large number of variable stars as a biproduct (Welch et al. 1997, Udalski et al. 1999a, Ansari et al. 2002) and the catalogues of Cepheid variables brought out by these projects (Beaulieu et al, 1995, Udalski et al. 1999b) have given insight into the pulsation properties of Cepheids.

In collaboration with the AGAPE (Andromeda Gravitational Amplification Pixel Experiment) group, we started Cousins R and I photometric observations of M31 galaxy in 1998 with an aim to search for microlensing events. Based on the observations of first 2 years, Joshi et al. (2001, hereafter referred as paper I) reported 8 variables, 7 of them were suspected as Cepheids and one Mira-like variable. In this paper, we extended our analysis to detect the variable stars using four years of observations. Details of our observations are given in next section while Sect. 3 outlines the detailed photometry of our data. The detection of variable stars is described in Sect. 4 which leads to search for some new Cepheids. The catalogue of Cepheids, their period-luminosity relation, colour-magnitude diagram along with brief discussion of each individual Cepheid are presented in Sect. 5. Other type of variables along with discussion and conclusion are given in the remaining part of the paper.

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2. Observation and image processing

The Cousins R and I broad band photometric observations were carried out at the f/13 Cassegrain 104-cm Sampurnanand Telescope of the State Observatory, Naini Tal. The CCD observations of the M31 galaxy were started in November 1998 using a 1024×1024 pixel^2 CCD covering $\sim 6' \times 6'$ field. A large size CCD containing 2048×2048 pixel^2 covering an area of $\sim 13' \times 13'$ was used for the observations in later years. The target field in the 2K ×2K ($\alpha_{2000} = 0^h43^m38^s$ and $\delta_{2000} = +41°09'.1$) is centered at a distance of about 15 arcmin away from the center of M31 galaxy. The detailed overview of telescope and instruments are given in paper I. A brief summary of the characteristic parameters of the two CCDs used for observations are given in Table 1. To minimize air mass effects, most of the observations were taken when zenith distance was ≤ 3 hour. We have accumulated 133 and 116 nights data in R and I filters respectively. Table 2 lists the date of observation, corresponding Julian date and total exposure time. A number of twilight flat field and bias frames were also taken during the observations. The average seeing during the entire observing runs was ∼2 arcsec.

Data reduction have been performed using the ESO MIDAS[1] and NOAO IRAF[2] softwares. Preliminary steps of the image processing include bias and flat fielding corrections. As the dark current during the maximum exposure time of a frame is negligible, it has not been corrected. The cosmic rays contaminations were removed independently from each frame using IRAF.

The observations were performed in 2×2 binned (0.74×0.74 arcesc^2) as well as in unbinned (0.37×0.37 arcesc^2) mode during different runs of observations. As the main aim of our observations is to search microlensing events in a combined data of Naini Tal (NTL) and AGAPE (observed with 1.3m MDM telescope at Kitt peak, Arizona), we aligned all the NTL images with respect to a

[1] Munich Image Data Analysis System (MIDAS) software is made and distributed by the European Southern Observatory

[2] Image Reduction and Analysis Facility (IRAF) software is distributed by the National Optical Astronomy Observatory

Table 1. Characteristic parameters of the two CCDs used for observations.

Size of CCD ($pixel^2$)	Field ($arcmin^2$)	Quantum Efficiency R(%)	Quantum Efficiency I(%)	Gain (e^-/ADU)	Readout Noise (e^-)	Pixel size (arcsec)
1024×1024	$\sim 6 \times 6$	35	31	2.96	4.1	∼0.37
2048×2048	$\sim 13 \times 13$	74	61	10.00	5.3	∼0.37

Table 2. Journal of the *RI* observations during the period 1998-2002. Exposure times of both *R* and *I* frames are given along with the number of frames.

Date	HJD	Exp. time (min)		Date	HJD	Exp. time (min)		Date	HJD	Exp. time (min)	
		R	*I*			*R*	*I*			*R*	*I*
21/11/1998	2451139	20 × 3	20 × 2	26/11/1999	2451509	20 × 2	-	08/12/2000	2451887	5 × 5	5 × 1
22/11/1998	2451140	20 × 3	20 × 3	27/11/1999	2451510	20 × 2	20 × 2	09/12/2000	2451888	5 × 5	5 × 5
25/11/1998	2451143	20 × 3	20 × 3	29/11/1999	2451512	20 × 2	-	11/12/2000	2451890	5 × 5	5 × 5
06/12/1998	2451154	20 × 3	20 × 3	01/12/1999	2451514	20 × 2	20 × 3	26/12/2000	2451905	5 × 5	5 × 1
07/12/1998	2451155	20 × 3	20 × 3	03/12/1999	2451516	-	20 × 2	05/01/2001	2451915	5 × 5	5 × 5
08/12/1998	2451156	20 × 3	20 × 3	05/12/1999	2451518	20 × 2	-	08/01/2001	2451918	5 × 5	5 × 5
12/12/1998	2451160	20 × 3	20 × 3	06/12/1999	2451519	20 × 2	20 × 2	11/01/2001	2451921	5 × 5	5 × 5
14/12/1998	2451162	20 × 3	20 × 3	09/12/1999	2451522	20 × 2	-	14/01/2001	2451924	5 × 5	5 × 5
15/12/1998	2451163	20 × 3	20 × 3	10/12/1999	2451523	20 × 2	-	15/01/2001	2451925	5 × 5	5 × 5
16/12/1998	2451164	20 × 3	20 × 3	11/12/1999	2451524	-	20 × 3	16/01/2001	2451926	5 × 5	5 × 5
17/12/1998	2451165	20 × 3	20 × 3	12/12/1999	2451525	20 × 2	-	17/01/2001	2451927	5 × 5	5 × 5
18/12/1998	2451166	20 × 3	20 × 3	13/12/1999	2451526	20 × 2	20 × 3	19/01/2001	2451929	5 × 5	5 × 5
19/12/1998	2451167	20 × 3	20 × 3	14/12/1999	2451527	20 × 2	20 × 3	05/10/2001	2452188	10 × 4	10 × 4
21/12/1998	2451169	20 × 3	20 × 3	15/12/1999	2451528	20 × 2	20 × 3	11/10/2001	2452194	10 × 5	10 × 3
22/12/1998	2451170	20 × 2	20 × 3	16/12/1999	2451529	20 × 2	20 × 3	12/10/2001	2452195	10 × 4	10 × 3
23/12/1998	2451171	20 × 3	20 × 3	18/12/1999	2451531	20 × 2	20 × 1	15/10/2001	2452198	10 × 4	10 × 3
24/12/1998	2451172	20 × 3	20 × 3	03/01/2000	2451547	-	20 × 3	16/10/2001	2452199	10 × 4	10 × 3
25/12/1998	2451173	20 × 3	20 × 3	04/01/2000	2451548	20 × 2	20 × 1	19/10/2001	2452202	10 × 4	10 × 3
26/12/1998	2451174	20 × 3	-	05/01/2000	2451549	20 × 2	20 × 2	20/10/2001	2452203	10 × 4	10 × 3
27/12/1998	2451175	20 × 3	20 × 3	06/01/2000	2451550	20 × 2	-	23/10/2001	2452206	10 × 4	10 × 2
28/12/1998	2451176	20 × 3	20 × 3	07/01/2000	2451551	20 × 2	20 × 3	24/10/2001	2452207	10 × 5	-
30/12/1998	2451178	20 × 3	20 × 3	11/01/2000	2451555	20 × 2	20 × 2	25/10/2001	2452208	10 × 4	-
31/12/1998	2451179	20 × 3	20 × 3	15/01/2000	2451559	20 × 2	-	30/10/2001	2452213	10 × 4	-
01/01/1999	2451180	20 × 3	20 × 3	16/01/2000	2451560	-	20 × 3	02/11/2001	2452216	10 × 4	10 × 1
02/01/1999	2451181	-	20 × 3	18/10/2000	2451836	5 × 5	5 × 5	03/11/2001	2452217	10 × 4	10 × 3
03/01/1999	2451182	20 × 3	-	19/10/2000	2451837	5 × 3	5 × 2	04/11/2001	2452218	10 × 5	10 × 4
10/01/1999	2451189	20 × 3	-	20/10/2000	2451838	5 × 3	5 × 5	07/11/2001	2452221	-	10 × 3
13/01/1999	2451192	-	20 × 3	23/10/2000	2451841	5 × 5	5 × 5	08/11/2001	2452222	10 × 4	10 × 2
14/01/1999	2451193	20 × 3	20 × 3	25/10/2000	2451843	5 × 3	5 × 5	11/11/2001	2452225	10 × 4	10 × 3
15/01/1999	2451194	20 × 3	20 × 3	27/10/2000	2451845	5 × 5	5 × 5	12/11/2001	2452226	10 × 4	-
16/01/1999	2451195	20 × 3	20 × 3	02/11/2000	2451851	5 × 5	5 × 5	15/11/2001	2452229	10 × 4	10 × 3
18/01/1999	2451197	20 × 3	-	04/11/2000	2451853	5 × 3	5 × 5	16/11/2001	2452230	10 × 5	10 × 3
25/01/1999	2451204	20 × 3	-	06/11/2000	2451855	5 × 3	5 × 5	17/11/2001	2452231	10 × 4	10 × 3
26/01/1999	2451205	-	20 × 3	13/11/2000	2451862	5 × 3	5 × 5	18/11/2001	2452232	10 × 4	10 × 3
22/10/1999	2451474	20 × 2	20 × 3	14/11/2000	2451863	5 × 3	5 × 5	22/11/2001	2452236	10 × 4	-
23/10/1999	2451475	20 × 2	20 × 3	17/11/2000	2451866	5 × 3	5 × 5	23/11/2001	2452237	10 × 4	10 × 3
24/10/1999	2451476	20 × 2	-	18/11/2000	2451867	5 × 3	5 × 3	28/11/2001	2452242	5 × 8	5 × 6
03/11/1999	2451486	20 × 2	20 × 3	19/11/2000	2451868	5 × 3	5 × 5	05/12/2001	2452249	5 × 4	5 × 2
04/11/1999	2451487	20 × 2	20 × 3	20/11/2000	2451869	5 × 3	5 × 5	10/12/2001	2452254	5 × 8	5 × 6
05/11/1999	2451488	20 × 2	-	21/11/2000	2451870	5 × 5	5 × 5	12/12/2001	2452256	5 × 6	-
09/11/1999	2451492	20 × 2	-	23/11/2000	2451872	5 × 5	5 × 5	13/12/2001	2452257	5 × 8	5 × 6
11/11/1999	2451494	20 × 2	-	25/11/2000	2451874	5 × 2	5 × 5	21/12/2001	2452265	5 × 8	5 × 6
12/11/1999	2451495	20 × 2	20 × 3	28/11/2000	2451877	5 × 5	5 × 4	22/12/2001	2452266	5 × 8	5 × 6
14/11/1999	2451497	20 × 1	-	29/11/2000	2451878	5 × 5	5 × 5	23/12/2001	2452267	5 × 8	5 × 6
15/11/1999	2451498	20 × 2	20 × 3	30/11/2000	2451879	5 × 5	5 × 5	24/12/2001	2452268	5 × 8	5 × 6
23/11/1999	2451506	20 × 2	20 × 3	02/12/2000	2451881	5 × 5	5 × 1	25/12/2001	2452269	5 × 8	5 × 6
25/11/1999	2451508	20 × 2	-	05/12/2000	2451884	5 × 5	5 × 5	01/01/2002	2452276	5 × 8	5 × 5

MDM reference image. The NTL images were scaled down or up to MDM pixel size (0.5×0.5 $arcsec^2$). These aligned images, in combination with AGAPE observations, will be used to search for microlensing events using the pixel method (Ansari et al. 1997).

3. Photometry

To check whether profile fitting photometry could be carried out on the modified NTL images, we compared the photometries carried out on original image and on modified images, the result of a particular night are displayed in Fig. 1. The comparison shows excellent agreement between the original image and modified images. Therefore we carried out photometry on the modified images. In order to increase signal to noise ratio, the images of a night were stacked together resulting one frame per filter per night. These images were used in further analysis.

Using DAOPHOT 'FIND' routine, we identified ∼4400 resolved stars in the reference frame at 4σ detection level. Stellar photometry for all the images in both filters has been carried out for these resolved stars in 'fixed-position mode' using DAOPHOT photometry packages as described by Stetson (1987). This provides us the same identification number for a particular star in all the frames therefore each star is identified by its number in all the frames. PSF was obtained for each frame using 25-30

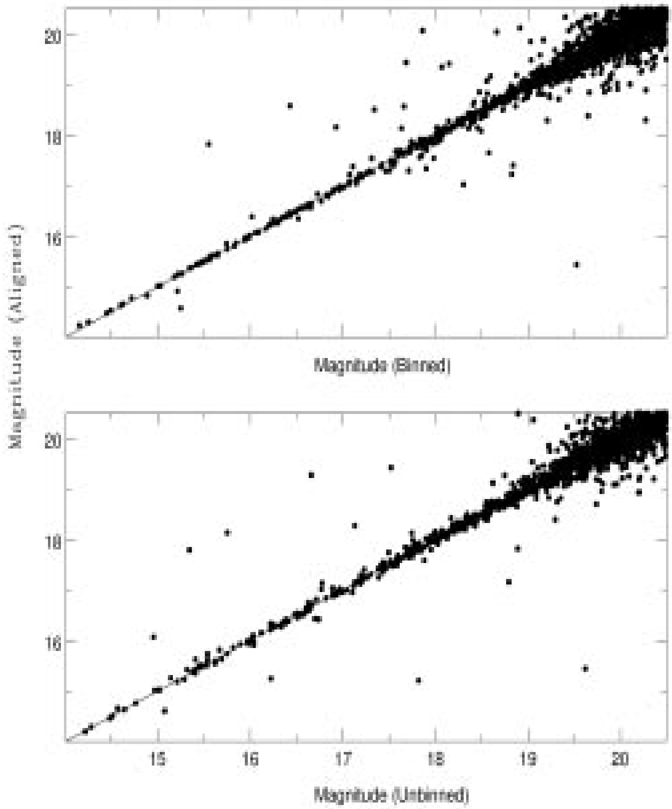


Fig. 1. The comparison of photometries carried out on original image (x-axis) and modified images images (y-axis). In the upper panel original pixel size (0.74 arcsec) was scaled down (0.5 arcsec), whereas in the lower panel the pixel size (0.37 arcsec) was scaled up (0.5 arcsec). The continuous line indicates the y = x line

uncontaminated stars. DAOPHOT/ALLSTAR (Stetson 1987) routine was used to calculate the instrumental magnitude of the detected stars for each individual frame. The internal errors estimated from the S/N ratio of the stars as output of the ALLSTAR are given in Table 3 as a function of brightness. The error become large ($>$ 0.1 mag) for stars fainter than $R \sim$20.0 mag.

Table 3. Internal photometric errors as a function of brightness. σ is the standard deviation per observation in magnitude.

Magnitude range	σ_R	σ_I
$\leq$14.0	0.01	0.01
14.0 - 15.0	0.01	0.01
15.0 - 16.0	0.01	0.01
16.0 - 17.0	0.01	0.02
17.0 - 18.0	0.02	0.04
18.0 - 19.0	0.04	0.06
19.0 - 20.0	0.07	0.13
20.0 - 21.0	0.15	0.33

3.1. Photometric Calibration

The absolute calibration has been done using Landolt's (1992) standard field SA98 observed on a good photometric night of 25/26 October, 2000. The airmass ranges from 1.3 to 2.1 during the observations. Atmospheric extinction coefficients determined from these observations are 0.11±0.01 and 0.08±0.01 in R and I filters and they have been used in further analysis. Thirteen standard stars having brightness range ($11.95 < V < 15.84$) and colour range ($0.09 < (R{-}I) < 1.00$) were used to derive following transformation equations.

$$\Delta(R-I) = (0.96 \pm 0.01) \times \Delta(r-i) \quad (1)$$

$$\Delta(R-r) = (0.03 \pm 0.03) \times (R-I) \quad (2)$$

where R and I are the Landolt standard magnitudes while r and i are the corresponding instrumental magnitudes. The zero point errors are about 0.02 mag in R and 0.01 mag in $(R-I)$. Equations (1) and (2) were used to generate 50 secondary standards in the target field observed on the same night by accounting the differences in exposure times and air-masses. A comparison of magnitude of these 50 secondary standards with that given in Magnier catalogue (Magnier et al. 1992) is presented in Fig. 2. A deviation of 0.03 ± 0.01 and 0.03 ± 0.05 magnitude was seen between two photometries in R and I filters respectively. To standardize the stars, differential photometry have been performed using these 50 stars with star under examination. We have rejected those secondary standards which were showing more than 3σ variation and process iterated three times and remaining 40 to 45 secondary standards were used to standardize our program star. A variation of ±0.1 mag was found around the mean value in the secondary stars itself during the whole observing runs which can be treated as a scatter in NTL photometry.

4. Detection of variable stars

4.1. Selection Criteria

We do not have all the observations in good photometric condition; therefore we have rejected all those data points showing photometric error of more than 0.2 mag. Further, for each star, the average DAOPHOT error and its standard deviation was calculated using the observations of that star on different nights. Measurements with errors exceeding to average error by more than 3σ were flagged as 'bad' and removed from further analysis. The whole procedure was repeated thrice. Normally 1 to 10 points were removed in this process. Because two different CCDs with different quantum efficiencies (see Table 1) and different exposure times (see Table 2) were used due to the observational limitations, limiting magnitudes were different in different years, consequently some stars could not be identified in one or other years of observations. Also all the stars of the reference frame were not present in all the other frames mainly due to trimming of side lobes of the images, re-

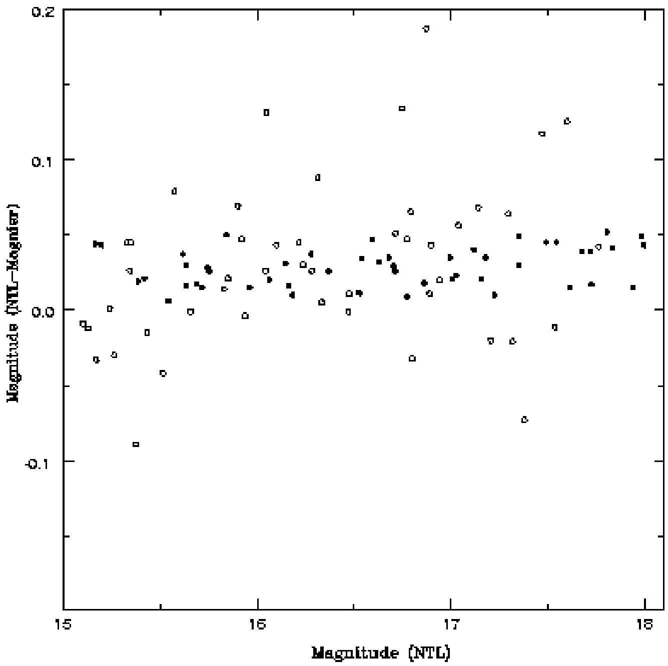


Fig. 2. A difference in the sense NTL minus Magnier (Magnier et al. 1992) in magnitudes is plotted for the 50 non-variable stars. Filled and open circles represent R and I magnitudes respectively.

jection of the part of the image during alignment, comparatively poor seeing on some nights, star falls over the bad pixels and contamination of stars by the saturated star on a better photometric night causing the spill-over of the flux on the neighboring pixels. We therefore have removed all those stars from further analysis which were not present in more than 40 observed nights. Considering errors in our observations, only stars showing variations > 0.1 magnitude around mean magnitude in 3 consecutive data points were used for further consideration. As there were comparatively larger error towards fainter end (see Table 3), we used only those stars to search for variability which were showing more than 5σ variation in 3 consecutive data points. These selection conditions have also discarded all those fake variations which were generated due to spill-over of the flux of the 3 bright saturated stars in our frames. Only R band photometric data was used for all these selections as the data sample in R filter (133) is larger than that in I filter (116). Also photometric errors in magnitudes are less in R filter (see Table 3). Using these selection criteria, we detected 360 variable stars in our field. Finally we searched the variability for these stars explicitly by visual monitoring. There is a bad pixels column in $2K \times 2K$ CCD, which affects a number of stars falls over the column. As the observations have been carried out on different nights, different stars fall over the bad pixels column, as a consequence, different stars were contaminated on different nights. Also on some good photometric nights having smaller seeing, the spill-over of the saturated stars transfer excess flux in many neighboring stars. Therefore, the unusual variations in the light curve of some stars on some of the nights can not be ruled out. We used I filter data only for the final analysis of the variables.

4.2. Classification of Variables

Two kind of variable stars were searched out of these 360 stars. (1) Periodic variables (e.g. Cepheids) for which estimation of period and mean magnitude was possible as described in the following subsections and (2) non-periodic or long period variables for which precise period could not be estimated due to partial phase coverage. For most of the these non-periodic variables, not even one cycle could be monitored in a single observing season. We therefore have classified the variable stars in two category: Cepheids and other variables.

4.3. Period determination

To find periods from unequally spaced data, we used a modified version of the period-searching program by Press and Rybici (1989) based on the method of Horne & Baliunas (1986). The data were initially phased for all periods between 5 and 600 days searched in an increment step of 0.6 day. To further refine the period, an increment of 0.1 day was used around thus derived period.

4.4. Mean magnitude

We calculated mean intensity and phase weighted apparent mean magnitude for all the variables as suggested by Saha & Hoessel (1990)

$$\overline{m} = -2.5 \log_{10} \sum_{\mathrm{i=1}}^{\mathrm{n}} 0.5(\phi_{i+1} - \phi_{i-1}) 10^{-0.4 m_i}$$

where n is the total number of observations, ϕ_i is the phase of i^{th} observation in order of increasing phase after folding the period. The equation requires non-existent entities ϕ_0 and ϕ_{n+1} which is set identical to ϕ_n and ϕ_1 respectively. The estimation of mean magnitude by the phase-weighted method is superior to an ordinary mean, which minimizes the systematic biases from loss of faint measurements in the mean magnitude (Saha & Hoessel 1990).

4.5. Astrometry

The following transformation equations were derived to convert pixel coordinates (X,Y) into celestial coordinates (α_{2000}, δ_{2000}) using 324 reference star positions from the USNO[3] catalogue:

$$\alpha = 11.099 - 0.000117X - 0.000147Y \quad (3)$$

$$\delta = 41.2082 - 0.000111X + 0.000088Y \quad (4)$$

[3] United State Naval Observatory

These coordinates agree within ∼0.1 arcsec with those given in Magnier catalogue (Magnier et al. 1992).

5. Cepheid Variables

Cepheid variables are post-main sequence stars occupying the instability strip in H-R diagram. They pulsate according to characteristic 'sawtooth' pattern, with periods ranging from a few days to more than 100 days. We have identified 27 Cepheid variables in the disk of M31 galaxy (Fig. 3). The Cepheids were identified by looking for the stars with light curves similar in appearances to known Cepheids of M31 galaxy. The period of the Cepheids was determined as described in Sect. 4.3. The periods estimated independently in two filters agrees very well for most of the Cepheids; however difference in the period exists for a few low period variables due to their low amplitude as well as comparatively larger photometric error in I-band. Therefore, the period calculated using R filter data was considered as the period of the star and phase in both R and I filters have been evaluated using this period. Moreover, once a period and amplitude are determined in R-band data, the phase and mean magnitude can be determined in I-band even with fewer observations (see Freedman 1988).

Since most of the Cepheids in the range of periods we have observed are believed to be in their second crossing of the instability strip, their period of pulsation is directly related to the stellar mass, and hence, to the main sequence life time of the star. Hence a rough estimate of the age of the star can be obtained from the observed period of the pulsation of the Cepheids. We have used the following relation given by Magnier et al. (1997b) to estimate the age of Cepheids:

$$\mathrm{logA} = 8.4 - 0.6\mathrm{logP} \qquad (5)$$

where A is the age of the Cepheid in years and P is the pulsation period in days. As Cepheids detected in our study have period ranging from ∼7.5 to 56 days, the age of the Cepheids varies from ∼22 to 75 Myrs with a peak of 48 Myrs. Though there is an uncertainty of ± 0.15 in log$A$ (Magnier et al. 1997b), this relation provides an indicative age of the Cepheids in M31, and hence some idea of the recent star formation history in the field of our observation.

In Table 4, we present characteristics of these 27 Cepheid variables detected in our study. The identification number of the star, celestial coordinate for J2000, phase weighted mean magnitude in both R and I filters, their colour, amplitude of variability in R filter, period, age of the Cepheid (estimated using Eq. 5) and total number of points in R filter used for the light curve study. The Cepheids are sorted in the increasing order of their periods. The reference to variability reported in the literature and corresponding period, if known, are listed in the last two columns. The period of the Cepheids spans from 7.46 to 56.02 days. Out of the catalogued 27 Cepheids,

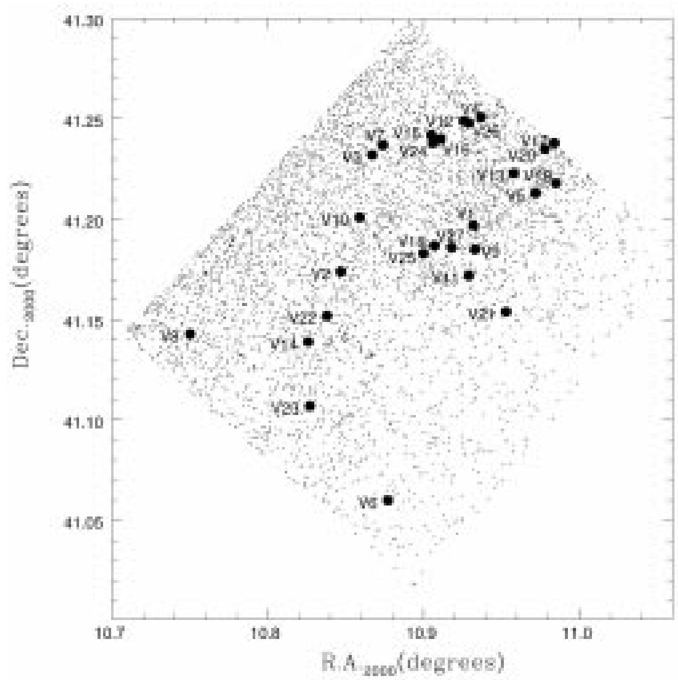
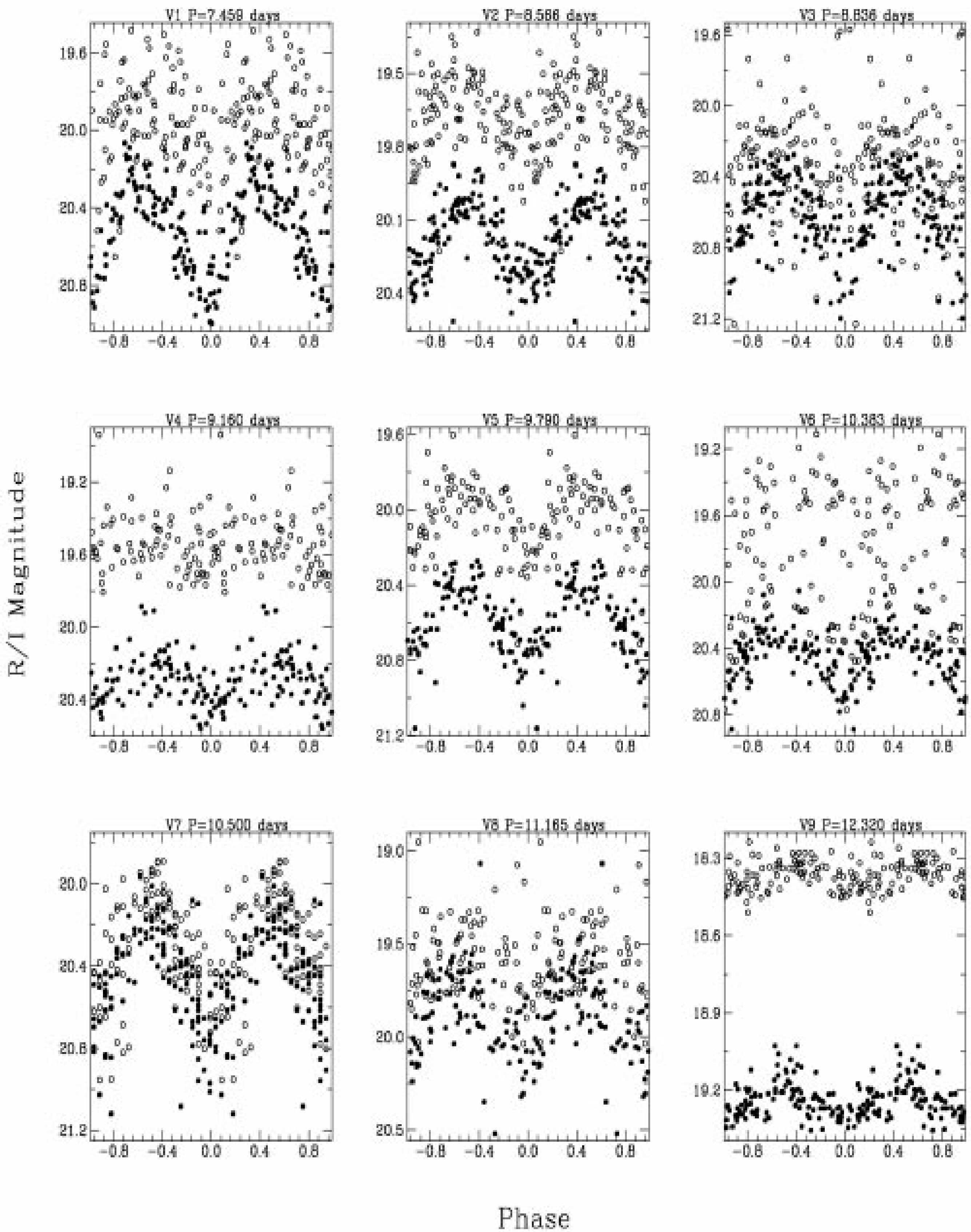


Fig. 3. Location of the 27 Cepheids identified in our data juxtaposed over the entire observed field of M31 galaxy. Small dots indicates the position of 4400 stars observed in our field.

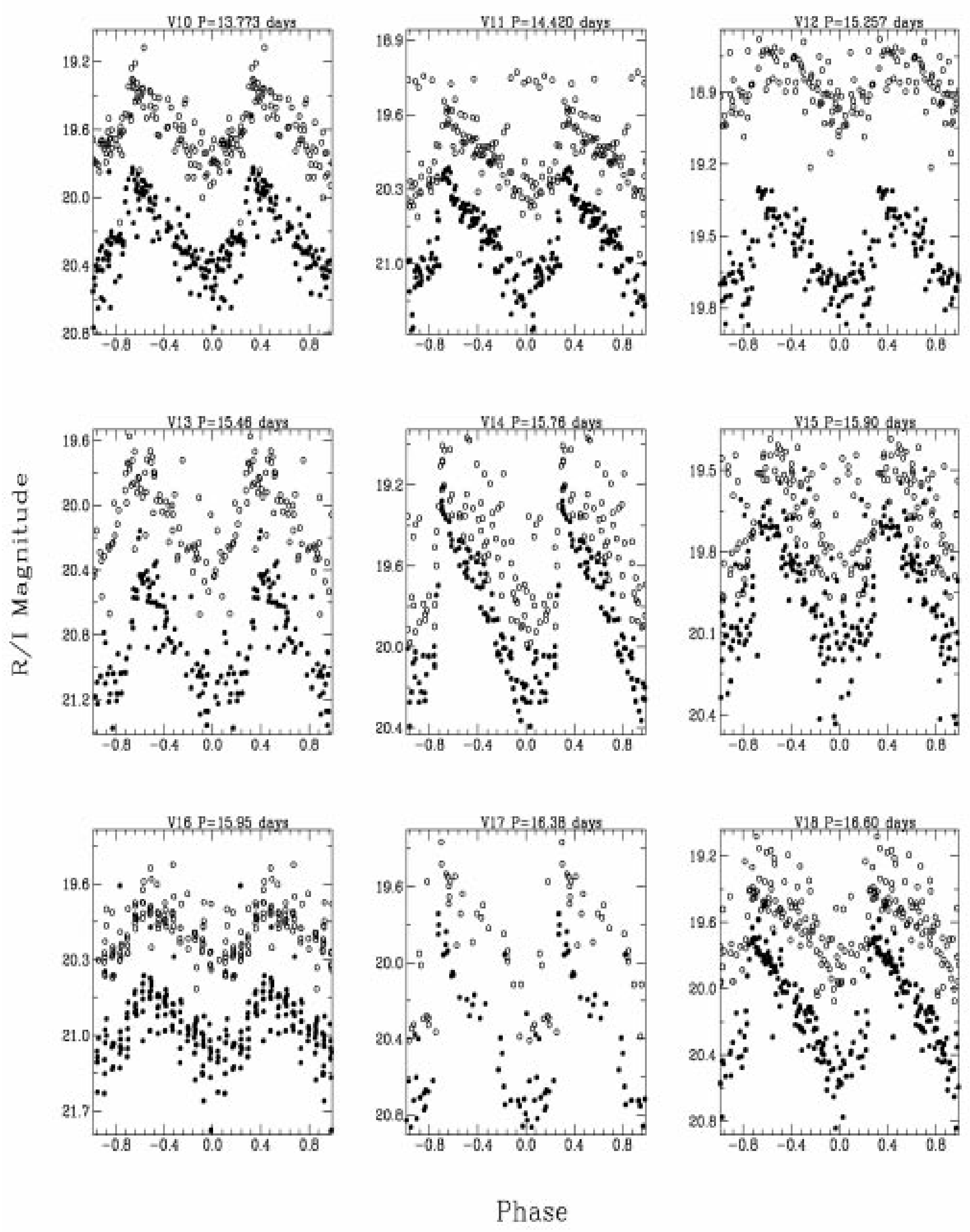
the variability is being reported for the first time for stars V23 and V25; moreover 13 of the variables are identified as Cepheids for the first time. The remaining 14 Cepheids have been known from earlier studies. The present data confirms their variability and our periods are generally in good agreement with the reported value.

In Fig. 4, we show the phase-magnitude diagram for all the 27 Cepheids in both R and I filters. The phase is shifted in such a way that minimum brightness in the phase light curve falls at zero phase. The I-band light curves show more scattering particularly for small period and low amplitude Cepheids. This could arise due to two reasons: (1) the amplitude of Cepheids decreases with increasing wavelength (e.g. Freedman et al. 1985). Infact Freedman (1988) found a ratio of 1.00:0.67:0.44:0.34 in amplitudes of B:V:R:I filters. As most of these Cepheids have pulsation of ∼0.1-0.2 magnitude in R filter, the amplitude of pulsation in I filter is even less and becomes comparable to the photometric errors. (2) the contamination due to neighboring stars (blending) in I filter is more than R filter because of smaller extinction towards longer wavelengths. As we have not taken account the effect of blending, more fluctuation in magnitude is expected in I filter which is most conspicuous in low period fainter Cepheids.

In Fig. 5, we have displayed a time-magnitude diagram for the Cepheid V24 which is discovered by us. The plot clearly demonstrates the periodic behavior of the Cepheid with a period of 28.78 days. This Cepheid has repeated about 12 times during the total period of 4 years of our


V1 P=7.459 days
V2 P=8.566 days
V3 P=8.636 days
V4 P=9.160 days
V5 P=9.790 days
V6 P=10.363 days
V7 P=10.500 days
V8 P=11.165 days
V9 P=12.320 days
R/I Magnitude
Phase

continue...


V10 P=13.773 days
V11 P=14.420 days
V12 P=15.257 days
V13 P=15.46 days
V14 P=15.76 days
V15 P=15.90 days
V16 P=15.95 days
V17 P=16.38 days
V18 P=16.60 days
R/I Magnitude
Phase

continue...

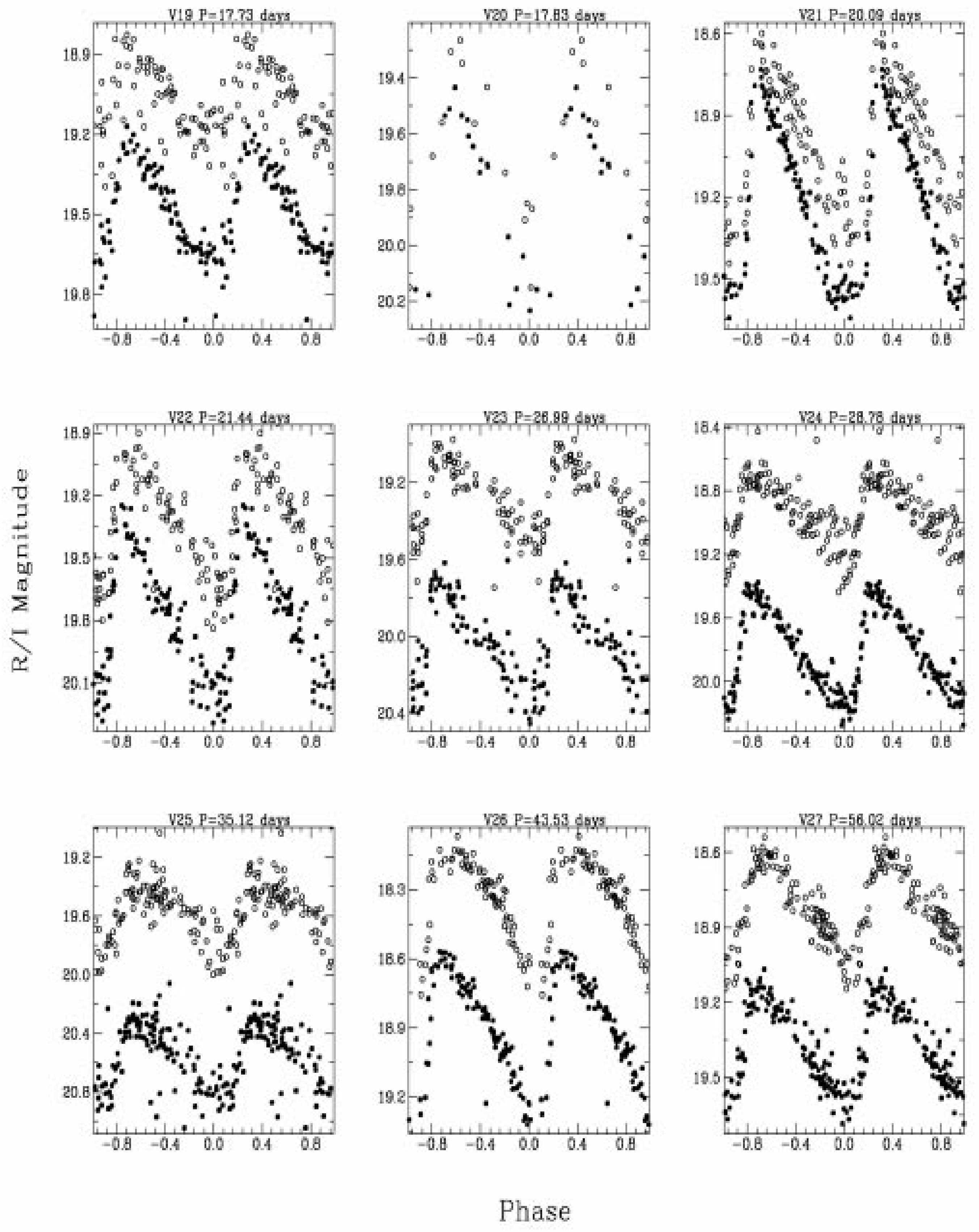


Fig. 4. Phase-magnitude diagram is plotted for 27 Cepheids detected in the present study. Filled and open circles represents R and I magnitudes respectively.

Table 4. A list of 27 Cepheids detected in our study with their characteristic parameters. Star identification by KAL99, Tomaney & Crotts (1996), MAG97 and Berkhuijsen, E. M. et al. (1988) are prefixed with K, TC, M and B respectively in column 11. The periods of the 14 Cepheids detected in corresponding catalogues are given in last column.

Star ID	α (deg)	δ (deg)	$\overline{R}$ (mag)	$\overline{I}$ (mag)	$\overline{R}$ - $\overline{I}$ (mag)	Δ_R (mag)	Period (days)	Age (Myrs)	N	Other Identification	Period (days)
V1	10.9321	41.1970	20.48	19.98	0.50	0.27	7.459±0.002	75	123	K V883	7.459
V2	10.8469	41.1737	20.17	19.69	0.48	0.15	8.566±0.003	69	124	TC 170	—
V3	10.8669	41.2320	20.61	20.28	0.33	0.22	8.836±0.004	68	120	TC 18	—
V4	10.9366	41.2503	20.28	19.54	0.74	0.11	9.160±0.008	67	86	K V1219	9.173
V5	10.9721	41.2128	20.56	20.04	0.52	0.19	9.790±0.005	64	92	K V2879	9.790
V6	10.8770	41.0601	20.43	19.76	0.67	0.15	10.383±0.009	62	93	TC 76	—
V7	10.8736	41.2367	20.42	20.27	0.15	0.28	10.500±0.004	61	123	TC 16	—
V8	10.7500	41.1426	19.89	19.55	0.34	0.17	11.17 ±0.01	59	95	M 65	25.0±5.0
V9	10.9341	41.1848	19.24	18.37	0.87	0.07	12.32 ±0.01	56	98	K V952	12.318
V10	10.8594	41.2004	20.21	19.60	0.61	0.26	13.773±0.006	52	126	TC 20	—
V11	10.9290	41.1715	20.77	19.84	0.93	0.48	14.420±0.006	51	116	TC 85	—
V12	10.9255	41.2489	19.57	18.87	0.70	0.16	15.26 ±0.01	49	96	K V635	15.255
V13	10.9582	41.2227	20.84	20.08	0.80	0.32	15.46 ±0.01	49	89	K V2286	15.464
V14	10.8259	41.1386	19.82	19.46	0.36	0.40	15.76 ±0.01	48	94	M 68	14.0±2.8
V15	10.9049	41.2419	19.93	19.58	0.35	0.22	15.90 ±0.01	48	121	TC 194	—
V16	10.9115	41.2396	20.79	19.91	0.88	0.30	15.95 ±0.01	48	126	TC 196	—
V17	10.9775	41.2348	20.28	19.74	0.54	0.40	16.38 ±0.02	47	47	K V3198	16.345
V18	10.9069	41.1868	20.12	19.60	0.52	0.39	16.60 ±0.01	47	124	B 4614	—
V19	10.9853	41.2176	19.47	19.09	0.38	0.21	17.73 ±0.01	45	91	K V3583	17.719
V20	10.9839	41.2374	19.83	19.60	0.23	0.32	17.83 ±0.03	45	18	K V3551	16.699
V21	10.9526	41.1540	19.20	18.99	0.21	0.35	20.09 ±0.01	42	96	TC 207	—
V22	10.8379	41.1514	19.74	19.31	0.43	0.39	21.44 ±0.02	40	96	M 69	13.0±2.6
V23	10.8272	41.1071	20.01	19.19	0.82	0.29	26.99 ±0.04	35	92	—	—
V24	10.9059	41.2379	19.78	18.92	0.86	0.34	28.78 ±0.02	33	127	TC 30	—
V25	10.9002	41.1823	20.55	19.57	0.98	0.23	35.12 ±0.05	30	121	—	—
V26	10.9293	41.2475	18.89	18.35	0.54	0.31	43.53 ±0.08	26	97	K V836	43.371
V27	10.9183	41.1856	19.36	18.82	0.54	0.22	56.02 ±0.08	22	124	K V164	56.116

observations, and the accuracy of our photometry is evident from the continuity of phase between the successive seasons. The Cepheids reported in our study are individually discussed in Sect. 5.6.

5.1. Comparison with earlier studies

Our target field in M31 has been observed only in a few earlier surveys. The V band photometric observations have been obtained by Magnier et al. (1997a, hereafter referred to as MAG97) for about 25 days. They have observed 9 fields of M31 galaxy and each field covered a region of $\sim$11 $\times$ 11 arcmin^2 in the sky. They found 130 Cepheids in the survey of M31 galaxy. As we have observed smaller field, only 3 of them are located in our field of observation and we have identified all of them. In Table 4, we have compared these stars with those found in our data set. One can easily notice a large discrepancy between the periods obtained in two surveys. We attribute it to insufficient observations by MAG97.

BVI photometry has been carried out by Kaluzny et al. (1999, hereafter referred to as KAL99) under the DIRECT project. Out of 35 Cepheids detected in DIRECT project in the field M31D, 11 are located in our field of observations. We have identified all of them in our study. We noticed that except in the case of V20, the periods determined in the two surveys are in excellent agreement. The discrepancy in the period for V20 appears to be due to inadequate data in the present study (see Table 4), mainly due to its location towards the edge of our field of observation. In Fig. 6, we have compared the two photometries in the I band, the only common filter in the two surveys. The mean difference in the I magnitude between the two surveys is 0.14±0.14 mag (excluding V9, for details see Sect. 5.6) indicating good agreement (within observational error) in the two studies.

5.2. Comparison with our previous study

We have reported 7 possible Cepheids and one mira-like variable in paper I after preliminary analysis of our two years data comprising $\sim 6\times6$ arcmin^2 field. We reanalysed those stars after 4 years of observations and a comparison is given in Table 5. This indicates that for six stars with period less than 30 days, the two parameters agree very well except for the faintest Cepheid V16. However, there is

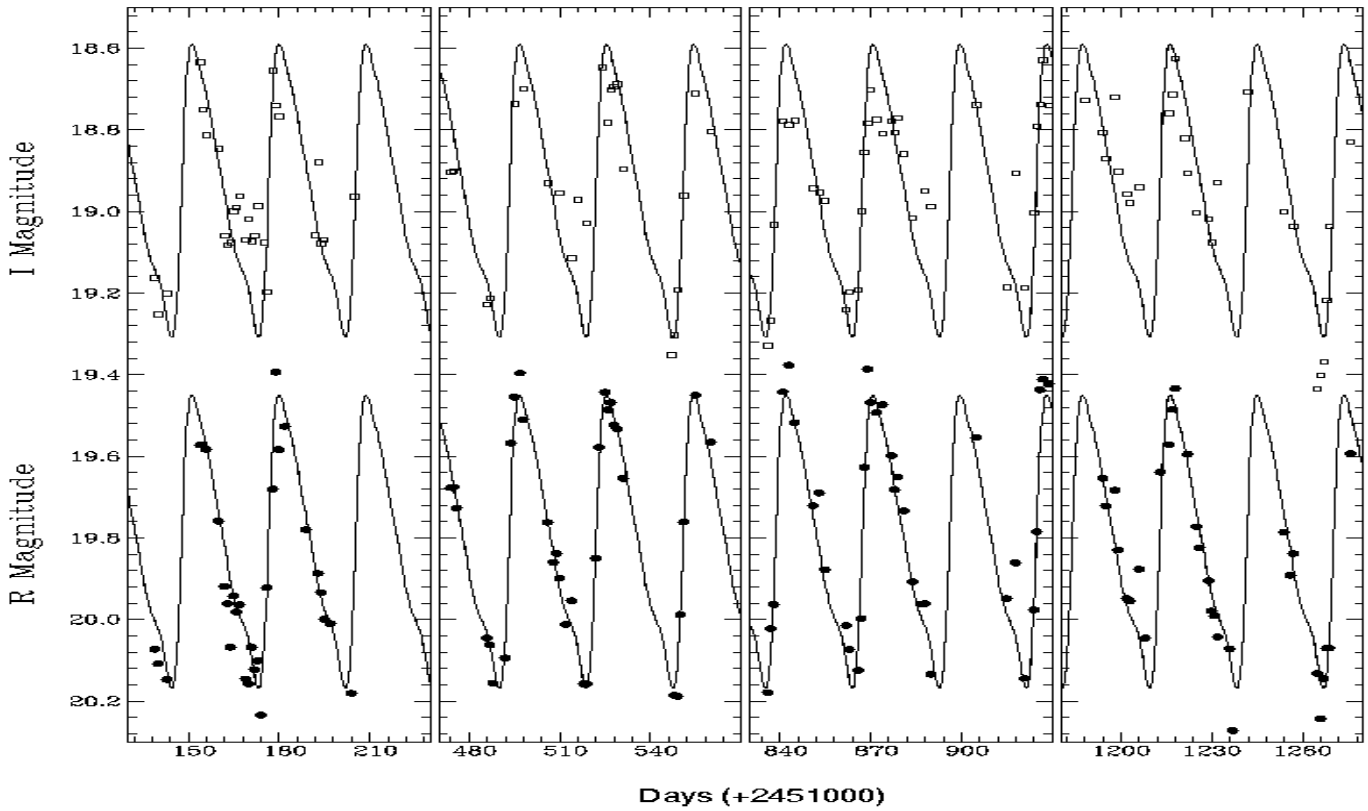


Fig. 5. Time-magnitude diagram for a newly detected Cepheid V24 (P=28.78 days) in both R and I filters. Jullian dates of observations are plotted in x-axis while magnitudes in R and I filters are plotted in y-axis.

Table 5. A comparison of the mean magnitudes and periods between our previous and present analysis of the variables reported in Paper I

ID		R (mag)		I (mag)		P (days)	
Old	New	Old	New	Old	New	Old	New
1	V7	20.36	20.42	20.19	20.27	10.48	10.50
2	V10	20.05	20.21	19.39	19.60	13.75	13.77
3	V16	20.92	20.79	20.09	19.91	15.26	15.95
4	V15	19.85	19.93	19.75	19.58	15.94	15.90
5	V18	20.02	20.12	19.51	19.60	16.50	16.60
6	V24	19.66	19.78	18.84	18.92	28.74	28.78
7	V27	19.26	19.36	18.69	18.82	56.50	56.02
8	V82	20.12	20.24	19.54	19.59	87.54	92.00

a small discrepancy in the period obtained for the two long period stars, the Cepheid V27 and other Mira-like variable V82 which we attribute to smaller data sample in our earlier analysis. A small difference in the phase weighted mean magnitudes of the two studies can be understood in terms of the photometric error in data.

5.3. The Period-Luminosity (P-L) Diagram

The Cepheid variables exhibit a stable periodic variability and there is an excellent correlation between their mean intrinsic brightness and pulsation period. Consequently, the Cepheid Period – Luminosity relation provide an important standard candles to measure distances to galaxies upto the Virgo Cluster, by comparison of their absolute magnitudes inferred from P-L relation with their observed apparent magnitudes.

Using a set of 32 LMC Cepheid variables, Madore & Freedman (1991) have obtained an equation of the ridge line in P-L diagram for Cousins R and I filters as:

$$M_R = -2.94(\pm0.09)(log\mathrm{P}-1) - 4.52(\pm0.04) \quad (6)$$

$$M_I = -3.06(\pm0.07)(log\mathrm{P}-1) - 4.87(\pm0.03) \quad (7)$$

The relation between period and luminosity of the classical Cepheids does not crucially depend upon metallicity. Freedman & Madore (1990) reported from the observations of Cepheids in four different regions of M31 that there is no significant dependence of the Period-Luminosity zero points on metallicity gradients. Kennicutt et al. (1998) reviewed the metallicity dependence on Cepheid distance scale under the HST Key Project and arrived at the same conclusion. We have therefore used the same hypothesis in our analysis.

The apparent mean magnitudes of 27 Cepheids are plotted as a function of logP in Fig. 7. The slope of the straight line is fixed as −2.94 and −3.06 for R and I filters respectively. Our I band photometry is not accurate enough for independent estimation of extinction towards

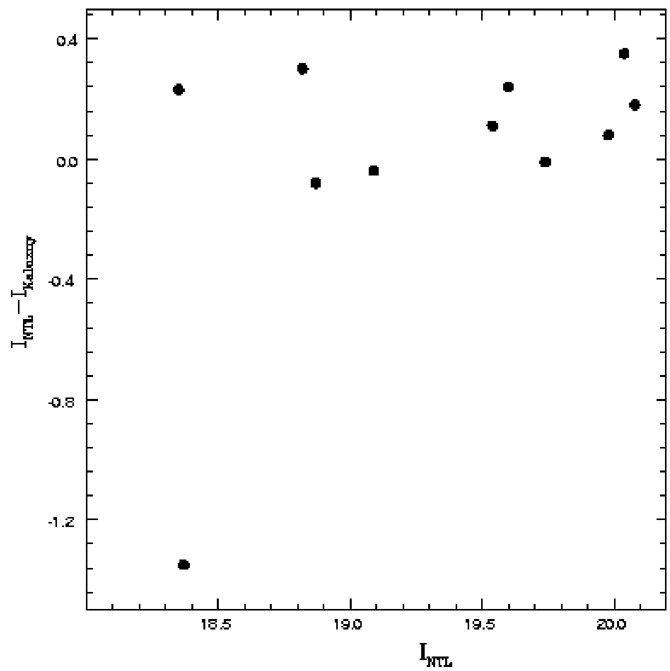


Fig. 6. Deviation in I magnitude in our data with that given in KAL99 for 11 common stars.

individual Cepheids. Consequently, based on a comparison between the observed $R-I$ and the values inferred from equations 6 and 7 we conclude that, by and large, differential extinction across the field of M31 observed by us is not significant. In the P-L diagram, the Cepheid V9 lies well above the P-L diagram in both R and I filters which suggest that this Cepheid might be oscillating in the first overtone mode which follows a different P-L relation than the classical Cepheids pulsating in the fundamental mode (Udalski et al. 1999c). The Cepheids V25 and V27 are located by about 1.0-1.5 mag below the ridge line in the P-L diagram and have considerably higher $R-I$ color, which, we attribute to higher extinction. However, V27 could be a Population II Cepheid variable. Therefore, we did not consider these three Cepheids for the zero points evaluation. Using remaining 24 Cepheids, we have drawn a zero points of 23.54±0.09 and 23.14±0.07 mag in R and I filters respectively. The dashed envelope lines are drawn 0.5 magnitude from the fitted line, representing the expected intrinsic scatter of P-L relation due to the finite width of the instability strip in the H-R diagram (Sandage 1958, Sandage & Tammann 1968) as well as the range of extinction corresponding to E(R-I) varying between 0.1 and 0.25 .

The above zero points give us a mean apparent distance modulus of (m-M)$_R$ = 25.12±0.09 and (m-M)$_I$ = 24.95±0.07 respectively in R and I filters without extinction correction. This yields us a mean colour excess of

$$E(R-I) = (m-M)_R - (m-M)_I = 0.17\text{mag} \quad (8)$$

Using the standard extinction law given by Cardelli et al. (1989) we found a total extinction (foreground+M31) of 0.65 and 0.48 mag in R and I filters respectively. Correcting the apparent distance modulus for the extinction, we obtain a distance modulus of 24.47±0.11 mag for the M31 galaxy (corresponds to a distance of 780±45 Kpc) which is consistent to a distance modulus of 24.44±0.10 mag determined by Madore & Freedman (1991).

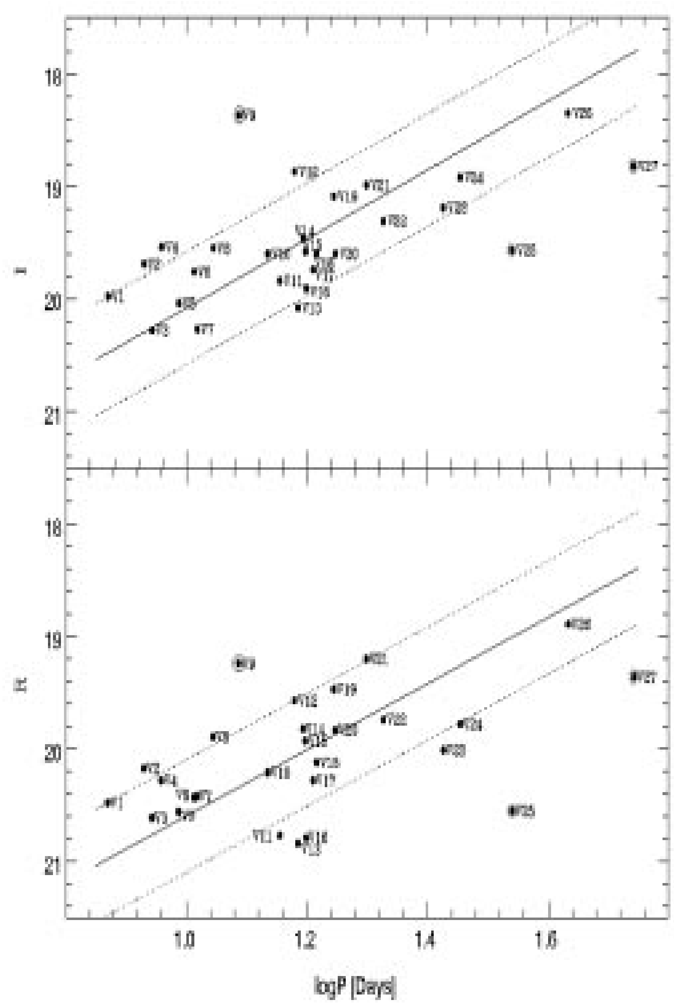


Fig. 7. Period-Luminosity relation for 27 Cepheids observed in our field. Lower panel indicates P-L relation for R filter while upper panel indicates for I filter. Filled circle: fundamental mode Cepheids; dotted circle: probably first overtone mode; asterisk: high extinction or possible Population II Cepheid. No correction for reddening have been applied to either data set. The slope of the straight line is set at dm/d log$P = -2.94$ and -3.06 for R and I filters respectively from the adopted calibration of the P-L relation. Only fundamental mode Cepheid have been used for the fitting. The dashed envelope lines have been drawn 0.5 magnitude from the straight line fit, expected as the intrinsic dispersion in Cepheid absolute magnitude caused by the finite width of the instability strip of the H-R diagram (Sandage 1958, Sandage & Tammann 1968).

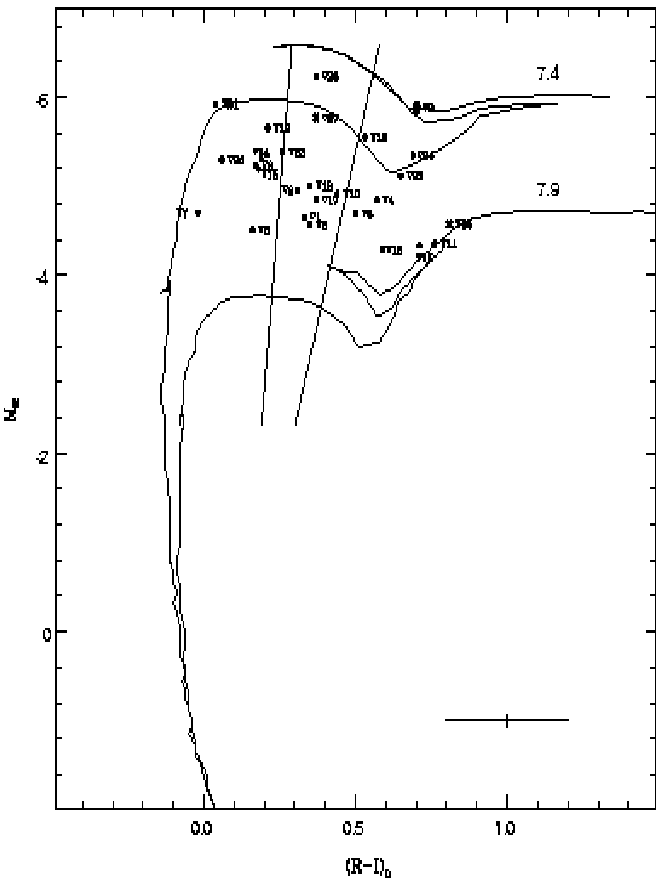


Fig. 8. The colour-magnitude diagram for 27 Cepheids discussed in the text. Symbols are the same as in Fig. 7. The solar metallicity isochrones by Bertelli et al. (1994) for logA = 7.4 and 7.9 are also plotted. Average magnitude of errors in observation are shown in the right bottom corner of the figure.

5.4. The Colour-Magnitude Diagram

The locations of these 27 Cepheids on the colour-magnitude diagram is shown in Fig. 8. The isochrones by Bertelli et al. (1994) for solar metallicity drawn for logA as 7.4 and 7.9 are also plotted which supports the age estimated from equation (5) except V9. As most of the detected Cepheids ranges in magnitude from 19 to 21 in R filter and 18 to 20 in I filter, there can be an error of ∼0.2 mag in the colour determination. The location of Cepheid V9 does not agree with its period determination given in Table 4 which is further discussed in Sect. 5.6.

5.5. Completeness Limit

We have identified 27 Cepheids in our observed region, in the period range of 7.5 to 56 days, at the magnitude limit R < 21 mag after four years of extensive monitoring. All of the Cepheids reported in earlier surveys have been detected in the present study so completeness of Cepheids at this magnitude is about 90% as ∼ 10% of the pixels in our CCDs are either bad or contaminated by bright stars. Therefore, some Cepheids in the region of present study might be still escaped from the detection. The number density distribution as a function of the period appears to follow the pattern of Milky Way for the period range of 8 to 60 days (Mazumdar, 2001). But since we had typically about 30 nights of observation per season, it is difficult to extract Cepheids of lower period, which are likely to have lower amplitudes even though their mean magnitude may be brighter than 21 mag in R.

5.6. Brief description of the Cepheids

The light curves of the 27 Cepheids detected in our study are discussed individually:

V1— This is the lowest period Cepheid detected in our study. The Cepheid V1 was reported earlier in KAL99. The period of the Cepheid is determined as 7.459±0.002 days in the present study which is same as that determined in the earlier reporting. Its light curves is well sampled and fairly smooth in R filter but shows small fluctuation in I filter. An independent period determination for this Cepheid on the INT data (obtained with 2.5m telescope at La Palma, Canarie Islands) using Lafler-Kinman periodogram (1965) estimated its period as 7.46 days which further confirms its obtained period.

V2— This is a newly detected Cepheid in our study with a period of 8.566±0.003 days. Though the light curve is smooth in R filter it shows a large fluctuation in I filter primarily because its amplitude of pulsation (A_I ∼0.1 mag) is comparable to the photometric error ($\sigma_I \sim 0.1$ mag). However, light curves of both filters, R and I have similar pattern.

V3— This newly detected Cepheid V3 is the faintest Cepheid variable of our list in I filter (20.28 mag). As the photometric errors below 20.0 magnitude are large (∼0.3 mag), most of the observational points have large errors. The period of this Cepheid is determined as 8.836±0.004 days. Although the Cepheid nature of the star is being reported for the first time in our study, the variability was already reported in Tomaney & Crotts (1996, hereafter referred as TC96).

V4— This Cepheid is earlier reported in KAL99 with a period of 9.173 days however we obtained a period of 9.160±0.008 days in the present study. This is one of the two stars which cannot be ascribed as a Cepheid variable purely on the basis of our data, however V-band photometry of the same star in KAL99 clearly indicates its Cepheid nature. The amplitude variation for this Cepheid in R filter is 0.11 mag and variation in I filter is smaller than this value while error in the I-band photometry at this magnitude ($M_I = 19.54$) is ∼0.1 mag which makes it difficult to find any trend in I-band phase light curve. A similar behavior was seen in I-band photometry of KAL99. This Cepheid could not be observed in our first year of observations due to smaller size CCD therefore light curve is comparatively less sampled.

V5— The Cepheid V5 is previously detected in the KAL99 with a period of 9.790 days which is in excellent agreement with the period (9.790±0.005) obtained by us. This Cepheid exhibits a well defined phase light curves in both filters. The Cepheid appeared only in last three years of observations but data sample is sufficient enough to determine the precise period and mean magnitude.

V6— This is a newly detected Cepheid in our study. The period of the Cepheid is determined as 10.383±0.009 days on the basis of last three years of observations. The I-band phase light curve is fairly noisy and no conclusion could be drawn from it alone; however its R filter counterpart is clearly showing a trend in the light curve. More monitoring is needed, particularly at shorter wavelengths (hence more amplitude variation), to determine more conclusive information about the Cepheid.

V7— This is one of the newly detected Cepheid for which phase weighted mean I magnitude is fainter than 20.0 mag. The period of the Cepheid is estimated as 10.500±0.004 days. The variable nature for the Cepheid was earlier reported by TC96. We also suspected it as a Cepheid in paper I with a period of 10.48 days after our preliminary analysis. The $(R-I)$ colour for this Cepheid is only 0.15 mag and hence, it is located away from the instability strip in the H-R diagram, which may be due to the large photometric error of ∼0.3 mag in colour. However, Cepheid nicely follow the P-L relation for the classical Cepheids.

V8— The Cepheid V8 was earlier reported in MAG97 with a period of 25.0±5.0 days. The large uncertainty in their period evaluation was due to insufficient data sampling and poor phase coverage. We obtained a period of 11.17±0.01 days using three years of observations. As this Cepheid is also a low amplitude (A_R) Cepheid, the phase light curve shows large fluctuations in I-band phase light curve. An accurate period could not be estimated for this Cepheid using INT data which suggests that it needs further investigation.

V9— This star does not show any clear Cepheid-like light curve in our R or I band data, though it is in the catalogue of Cepheids in KAL99. We included this Cepheid in our list of Cepheids mainly on the basis of its V-band phase light curve in KAL99. Our data gives a period of 12.32±0.01 days which is in agreement with earlier reported period of 12.318 days by KAL99. The I-band magnitude obtained in the two photometries differs by 1.35 mag as shown in Fig. 3 which is exceptionally large but similar behavior in both R and I band in our data supports our photometry. This star falls well above the normal P-L relation (see Fig. 7) in both R and I filters and we suspect that either this is a Cepheid oscillating in first overtone or it is a red variable .

V10— This Cepheid V10 is reported for the first time with a period of 13.773±0.006 days. However, its Cepheid-like behavior with a period of 13.75 days was reported by us in paper I. The light curves of the Cepheid are rich sampled and smooth in both R and I filters which confirms its precise period determination.

V11— This is also a newly discovered Cepheid. The period of the Cepheid V11 is estimated as 14.420±0.006 days. This Cepheid shows the maximum amplitude variation of 0.48 mag in R filter and is one of the reddest star observed in our catalogue of 27 Cepheids.

V12— The Cepheid V12 was earlier reported in KAL99 with a period of 15.255 which is close to our period determination of 15.25±0.01 days from the phase light curve obtained during three years of our observations.

V13— This is the faintest Cepheid (R = 20.84) detected in our study. The Cepheid V13 was earlier reported in KAL99 having a period 15.464 days while we obtained a period of 15.46±0.01 days for it after three years of observations which in accordance with earlier reported period. This Cepheid is lying outside the ±0.5 mag of ridge line in P-L diagram in both filters (see Fig. 7), which is not surprising in view of the redness and consequent large extinction. However, the phase magnitude diagram as well as its location in the colour-magnitude diagram (Fig. 8) support its Cepheid behavior.

V14— Cepheid V14 was discovered in earlier survey of MAG97 with a period of 14.0±2.8 days. We refined this period to 15.76±0.01 with our rich sample of data and better phase coverage.

V15— The Cepheid V15 is newly detected in our study with a period of 15.90±0.01 days however a period of 15.94 days Cepheid was approximated in paper I. The variable nature of the star have been reported earlier in TC97.

V16— This is a newly discovered Cepheid with the period obtained as 15.95±0.02 days. The variable nature of the star is earlier reported in TC96. After our preliminary analysis of first two years observations, we suspected it as a Cepheid with a period of 15.26 days. A large fluctuation in 1998 observations along with the undersampling of data might be responsible for underestimation of its period in our earlier study.

V17— The Cepheid is earlier reported in KAL99 with a period of 16.345 days while we obtained a period of 16.38±0.02 days. Both values are in good agreement despite the light curve is fairly under-sampled in our data set and most of the points are appeared in only 1999 observations. The Cepheid falls at the edge of our frame therefore its observations are missed on most of the nights. However, the data points are well separated in phase and most of the observations fall either at maximum or minimum side of the light curve thus the light curve could be credibly constrained.

V18— This is a newly discovered Cepheid with a period of 16.60±0.01 days while paper I reported it as a possible Cepheid of period 16.50 days using first two years of monitoring. A large number of points apart from the well sampled phase light curves in both R and I filters lend credibility to the new obtained period. The nature of the variability of the star was first reported in Berkhuijsen et al. (1988).

V19— The Cepheid V19 was earlier discovered by KAL99 with a period of 17.719 days. We obtained a period of 17.73±0.01 days using three years of observations which is in consistent with earlier value.

V20— KAL99 obtained a period of 16.999 days for this Cepheid while we obtained a period of 17.83±0.03 days using 18 data points. The light curve for this Cepheid is extremely under-sampled and poorly distributed in phase in our data. This star was left out during our initial cut-off selection criteria (total observed points should be more than 40) but after comparison with KAL99, we found this star in our original reference data file. Therefore, we produced the light curve of the star with all the available points and deduced the period and mean magnitude. However, we get sufficient points towards maximum and minimum phase, mostly came from the 1999 observations due to which the light curve could be credibly generated. The discrepancy in the period between two surveys is due to the under-sampling of our data although the nature of the phase light curves confirms its Cepheid behavior.

V21— This Cepheid was discovered in our study however variability in the star was already known by TC96. The period obtained using three years of data is 20.09±0.01 days. The same period estimated for the Cepheid using INT data further confirms its period.

V22— This Cepheid was previously detected by MAG97 where period was approximated to 13.0±2.6 days. Using our 3 years data, we obtained a period of 21.44±0.02 days. Though a large discrepancy is seen in the two periods, better data sampling and a conspicuously good phase light curves deduced with the period 21.44 days in both filters lend support to our estimated period. A period determination of 21.44 days from INT data further supports our value.

V23— This is one of the two stars on which the variability itself was reported by us. The Cepheid V23 is discovered in the present study with a period of 26.96±0.04 days using 2 years of observations while we modified its period to 26.99±0.04 days after four years of observations. A small bump in the falling branch can be seen in both filters.

V24— This is a new Cepheid for which variability was reported by TC96 but its Cepheid nature was suspected in our previous paper with a period 28.74 days using first two years of observations. However, we refined its period to 28.78±0.02 days using four years of observations. A time-magnitude diagram for the Cepheid is also plotted in Fig. 5 using this period.

V25— This is also another star in which variability is being reported for the first time. The period of this newly detected Cepheid using four years observations is obtained as 35.12±0.05 days. An exceptionally large value of $(R-I)$ colour of 0.98 mag was observed in this star, and consequently, the Cepheid deviates towards the fainter side in the P-L diagram in both filters

V26— This is the brightest Cepheid observed in our study. We obtained a period of 43.53±0.08 days using three years of observation while KAL99 reported its period as 43.371 days.

V27— This is the longest period Cepheid in our sample. We obtained its period as 56.02±0.08 days using four years of observations. For the same Cepheid, KAL99 obtained a period of 56.116 days while we earlier reported its period as 56.5 days in paper I after first two years of observations. This Cepheid is also shifted downwards in the P-L diagram in both filters possibly due to the large extinction or, it could even be a Population II type Cepheid.

5.7. Location of the Cepheids

The locations of the Cepheids (see Fig. 3) indicate that most of them are towards the inner side of M31 galaxy (bulge direction), where, possibly, the star formation was active a few million years ago. This inference is further supported by the fact that, the early type supergiants detected in our field (($R-I < -0.1$ and R between 16 and 19 mag) also occupy the same strip where the Cepheids are found. So it is tempting to suggest that we are possibly tracing one of the spiral arms of M31 galaxy. However, within the strip, we are unable to see any systematic variation in the extinction though four Cepheids show excessive reddening.

6. Other variables

In addition to the Cepheid variables reported in our field, 333 other variable stars were also found in the present study. Most of them appeared to be irregular variables however 115 stars were found periodic for which we could determine approximate period and magnitude. With the follow-up observation of these long-period variables, we would be able to estimate period and mean magnitude more accurately. In Table 4, we have given the identification number, celestial coordinates, mean magnitude in R and I filters and amplitude variation of these 333 stars in R filter. In the seventh column, we identify periodic star as P, nova as No and binary as BI and rest of the stars seems to be Irregular variable. The period of periodic variables are given in the parenthesis of the same column. In the last column we have given the identification of the stars which have already been found in earlier surveys compiled from SIMBAD[4] archive. Stars are listed in increasing order of Right Ascension. Out of these 333 stars, 32 were already identified in various categories and 115 stars are found as periodic in our data. We also identified 2 stars namely V48 and V224 as a possible nova observed during falling phase of their light curve in our observations. The

[4] http://simbad.u-strasbg.fr/Simbad

light curve of V224 is given in Fig 9(a). Two stars namely V177 and V285 are suspected as a binary and light curve for one of them is shown in Fig 9(b). In Fig. 9(c), we have given the light curve of a periodic star V155 with period ∼236 days while the light curve of an irregular variable V253 is shown in Fig 9(d). The *RI* photometric data of these 333 stars are available in electronic form either from authors or at the CDS via anonymous ftp.

7. Conclusion

We have been monitoring a $\sim 13 \times 13$ arcminute^2 region of the disk of M31 galaxy since 1998. Using 141 nights of observation spanning a period of ∼1200 days, we have detected 27 Cepheids among which variability in 2 stars has been found for the first time. We have established the Cepheid nature of 13 variables in the sample, while we confirm the period and nature of variability in the other 14 stars. The period obtained for these Cepheids ranges from ∼7.5 to 56 days. The extensive data has enabled us to obtain accurate period and mean magnitude of a sample of Cepheids, which we believe to be reasonably complete within *R* magnitude of 21. The detected Cepheids range in age from 22 Myrs to 75 Myrs and occupy a strip where the early type supergiants too are located. Using the period-luminosity relation of the Cepheids, we derive a distance of 780±45 Kpc for M31 galaxy. There could be slight additional uncertainty in the distance due to variable extinction within the observed region.

In addition to Cepheids, we also detect 333 variable stars in the field under investigation. Out of them 115 are periodic variables, 2 suspected eclipsing binaries, 2 as a possible nova and most of the remaining 214 stars appear to be irregular variables.

We have thus demonstrated once more that a meter class telescopes like ours can play important role in the study of variable stars provided large amount of telescope observing time is given. These data are also valuable for the search of gravitational microlensing events towards M31 galaxy. We are in the process of identifying lensing candidates in our target field and detailed study shall be presented in the forthcoming publication.

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Table 6. The celestial coordinates of 333 variables detected during our observations.

Star ID	α_{2000} (deg)	δ_{2000} (deg)	R (mag)	I (mag)	Δ_R (mag)	Type (days)	Status (old)	Star ID	α_{2000} (deg)	δ_{2000} (deg)	R (mag)	I (mag)	Δ_R (mag)	Type (days)	Status (old)
V28	10.7264	41.1578	20.16	19.25	0.50			V111	10.8244	41.0719	20.52	19.31	0.22		
V29	10.7357	41.1657	18.38	17.91	0.17			V112	10.8243	41.1331	20.63	19.75	0.50	P(202)	
V30	10.7393	41.1673	20.27	19.25	0.59			V113	10.8263	41.1076	19.62	18.26	0.23		
V31	10.7448	41.1399	20.20	19.32	0.37	P(144)	No	V114	10.8267	41.1124	20.73	18.72	0.68		
V32	10.7488	41.1219	20.59	19.73	1.70	P(131)		V115	10.8274	41.2000	20.10	19.47	0.38	P(62)	
V33	10.7502	41.1657	20.60	19.96	0.32		Em0	V116	10.8269	41.2250	20.73	19.44	0.69	P(151)	
V34	10.7518	41.1171	20.22	18.16	0.46	P(257)		V117	10.8270	41.2336	20.43	19.45	0.61	P(213)	
V35	10.7526	41.1185	20.69	19.70	0.44	P(135)		V118	10.8285	41.0952	20.75	20.11	0.48		
V36	10.7555	41.1456	19.25	18.30	0.20			V119	10.8279	41.2209	20.65	19.41	0.73		
V37	10.7554	41.1518	20.55	19.97	0.60			V120	10.8307	41.1522	18.90	17.63	0.13		
V38	10.7581	41.1697	21.07	19.91	0.92	P(133)		V121	10.8309	41.1781	21.10	19.93	0.79		
V39	10.7598	41.1486	20.18	19.30	0.47			V122	10.8306	41.2308	20.22	19.14	0.40	P(92)	
V40	10.7618	41.1375	20.48	19.66	0.92			V123	10.8310	41.2338	20.57	19.16	0.48		
V41	10.7655	41.1497	20.49	19.49	0.57	P(153)		V124	10.8317	41.2447	20.44	19.49	0.50		
V42	10.7673	41.1522	20.37	19.38	0.76	P(129)		V125	10.8330	41.1595	20.79	19.99	0.63		
V43	10.7681	41.1392	19.77	19.30	1.20			V126	10.8329	41.1977	20.96	19.79	0.63	P(202)	
V44	10.7679	41.1572	20.65	19.56	0.95			V127	10.8338	41.0963	20.81	19.81	0.78	P(145)	
V45	10.7678	41.1737	20.79	19.48	0.62	P(217)	Em0	V128	10.8336	41.2234	20.92	19.40	0.80	P(224)	
V46	10.7697	41.1942	20.70	19.43	0.90			V129	10.8341	41.2479	20.70	19.82	0.78		
V47	10.7710	41.1032	21.20	19.58	1.16			V130	10.8348	41.1596	20.14	19.08	0.46		
V48	10.7741	41.1284	17.59	16.42	0.32	No		V131	10.8353	41.1982	20.97	19.92	1.07	P(202)	
V49	10.7753	41.1232	20.56	19.55	0.91		Em0	V132	10.8363	41.0888	19.30	17.86	0.24		
V50	10.7746	41.1773	19.55	19.26	0.26			V133	10.8359	41.1062	20.22	19.61	0.34		
V51	10.7745	41.1947	19.98	18.97	0.37	P(161)		V134	10.8375	41.1341	20.75	19.80	0.41		
V52	10.7756	41.1802	20.87	19.71	0.66	P(225)		V135	10.8365	41.1923	20.69	19.45	0.67	P(157)	
V53	10.7763	41.1908	20.91	19.52	0.94			V136	10.8388	41.0711	21.34	20.18	0.82	P(253)	
V54	10.7791	41.1402	20.96	19.69	1.06			V137	10.8389	41.1793	20.76	20.38	0.73	P(163)	
V55	10.7802	41.1844	21.01	19.70	0.65	P(227)		V138	10.8391	41.2449	20.43	19.26	0.38		
V56	10.7810	41.1929	20.53	18.91	1.08			V139	10.8389	41.2484	20.37	19.49	0.31		
V57	10.7818	41.1325	20.46	19.70	0.39			V140	10.8398	41.1597	20.81	19.40	0.67		
V58	10.7833	41.1864	20.07	19.10	0.30	P(212)		V141	10.8398	41.1974	21.25	20.91	1.00		
V59	10.7836	41.1544	20.83	20.14	3.23			V142	10.8411	41.0804	20.88	19.87	0.67	P(215)	
V60	10.7840	41.1692	19.72	18.48	0.33			V143	10.8407	41.1602	20.99	19.52	0.60	P(249)	
V61	10.7848	41.1915	20.66	19.46	0.93			V144	10.8419	41.1682	21.56	19.91	0.91		
V62	10.7863	41.1012	18.67	17.27	0.27			V145	10.8434	41.1744	18.26	17.56	0.15		
V63	10.7863	41.1652	20.66	19.62	0.38			V146	10.8427	41.1936	20.97	19.61	0.58		
V64	10.7878	41.1242	20.46	19.50	0.64	P(249)		V147	10.8431	41.2280	20.49	19.98	0.58		
V65	10.7894	41.1004	21.24	20.33	0.96			V148	10.8451	41.1313	20.99	18.77	0.82		
V66	10.7889	41.1933	20.77	19.87	1.00	P(274)		V149	10.8446	41.2060	20.51	19.42	0.82	P(168)	
V67	10.7909	41.1270	20.41	19.26	0.72			V150	10.8450	41.2472	20.70	19.94	0.82		
V68	10.7914	41.1585	20.65	19.20	0.78			V151	10.8458	41.0995	20.23	19.44	0.75		
V69	10.7906	41.1700	20.47	19.55	0.47			V152	10.8465	41.1704	20.20	19.61	0.62		
V70	10.7919	41.1417	21.04	19.91	1.10	P(158)	Em0	V153	10.8467	41.1822	20.97	20.11	0.96		V
V71	10.7928	41.0913	20.49	19.64	0.51			V154	10.8467	41.2273	20.61	20.12	0.46		
V72	10.7932	41.1703	21.03	19.87	0.93			V155	10.8493	41.1980	20.83	19.97	1.18	P(236)	
V73	10.7931	41.1812	20.47	19.50	0.52			V156	10.8511	41.1027	19.82	18.20	0.43		V
V74	10.7952	41.0932	21.47	20.17	1.01	P(214)		V157	10.8514	41.1099	20.72	19.72	0.55	P(260)	
V75	10.7978	41.0898	20.57	19.83	0.43			V158	10.8510	41.1525	19.78	19.14	0.39	P(276)	
V76	10.7990	41.1777	19.93	19.28	0.76			V159	10.8508	41.2077	19.65	18.01	0.30		
V77	10.8002	41.1434	21.41	19.83	0.78			V160	10.8513	41.2520	20.98	20.05	1.35		
V78	10.7998	41.1932	20.69	19.42	0.54			V161	10.8523	41.1316	21.19	19.51	1.09		
V79	10.8005	41.1943	20.04	18.68	0.46			V162	10.8521	41.1703	20.57	19.29	0.55		
V80	10.7998	41.2090	20.42	19.66	0.67			V163	10.8524	41.1976	20.97	19.90	0.63		
V81	10.8006	41.1864	20.92	19.78	1.01	P(202)		V164	10.8534	41.1616	20.07	19.38	0.56		
V82	10.8017	41.1885	20.24	19.59	0.77	P(92)		V165	10.8534	41.2002	20.97	20.07	0.65	P(143)	
V83	10.8024	41.1932	20.86	19.82	0.64	P(257)		V166	10.8526	41.2072	20.87	20.00	0.63	P(122)	
V84	10.8029	41.1500	20.71	19.34	0.74			V167	10.8525	41.2418	21.18	19.96	2.10		
V85	10.8032	41.2145	21.19	19.59	0.75	P(268)		V168	10.8536	41.0816	19.58	18.34	0.29	P(125)	
V86	10.8041	41.2220	20.26	19.32	0.70			V169	10.8542	41.2421	20.84	19.10	0.88		As
V87	10.8046	41.0922	20.80	19.95	0.52			V170	10.8550	41.1017	18.68	17.27	0.30	P(260)	
V88	10.8047	41.2092	20.79	19.28	1.11			V171	10.8565	41.1804	20.81	20.12	0.87		
V89	10.8063	41.2018	20.54	19.25	0.83	P(186)		V172	10.8565	41.0901	21.65	20.53	0.95	P(142)	
V90	10.8068	41.2026	21.15	20.03	1.18			V173	10.8581	41.1833	20.80	19.81	1.14	P(96)	
V91	10.8082	41.1087	20.00	18.57	0.30		Em0	V174	10.8577	41.2540	20.81	19.66	0.73	P(220)	
V92	10.8083	41.2016	20.77	19.89	0.66			V175	10.8587	41.2195	21.16	19.87	0.86	P(139)	
V93	10.8077	41.2221	20.04	18.86	0.41			V176	10.8597	41.1185	20.88	19.68	0.84	P(177)	
V94	10.8092	41.2172	20.50	19.33	0.85			V177	10.8596	41.1660	19.55	19.22	0.77	BI 101	
V95	10.8112	41.0788	20.82	19.72	0.47			V178	10.8600	41.1988	20.56	19.64	0.45		
V96	10.8113	41.1870	20.77	19.74	0.50	P(145)	V	V179	10.8622	41.0469	20.50	19.65	0.73		
V97	10.8106	41.2246	20.64	19.87	0.51			V180	10.8620	41.1524	20.85	19.85	0.74	P(237)	
V98	10.8117	41.0746	19.61	18.09	0.21			V181	10.8624	41.1657	20.59	19.57	0.51		V
V99	10.8130	41.1866	20.01	18.95	0.87		V	V182	10.8623	41.2732	19.98	19.07	0.62	P(171)	
V100	10.8126	41.2058	20.22	19.02	0.76			V183	10.8630	41.2339	20.70	19.49	0.95		
V101	10.8125	41.2100	20.70	19.93	0.45	P(254)	Lev	V184	10.8639	41.1026	18.74	18.51	0.20	P(65)	
V102	10.8145	41.0930	20.96	20.43	0.56	P(138)		V185	10.8651	41.0923	19.77	18.41	0.23		
V103	10.8140	41.1180	20.46	19.92	0.49			V186	10.8650	41.2762	20.80	19.26	0.63		
V104	10.8145	41.1432	20.35	19.18	0.50			V187	10.8657	41.1331	20.42	18.80	0.39		
V105	10.8168	41.1270	20.97	20.32	0.79			V188	10.8657	41.2259	21.33	20.47	0.79		
V106	10.8183	41.0956	20.41	19.34	0.58	P(218)		V189	10.8655	41.2319	20.93	20.20	1.45	P(159)	V
V107	10.8194	41.2327	20.53	19.36	0.73			V190	10.8666	41.1227	20.00	19.18	0.33		
V108	10.8212	41.2130	21.42	20.09	1.56	P(217)		V191	10.8679	41.1701	20.31	19.40	0.46	P(130)	
V109	10.8216	41.0774	20.73	19.31	0.76	P(227)		V192	10.8682	41.2727	19.74	19.02	0.48		
V110	10.8218	41.2078	20.59	20.06	0.43		GIC	V193	10.8689	41.1606	21.04	20.23	0.95		

Star ID	α_{2000} (deg)	δ_{2000} (deg)	R (mag)	I (mag)	Δ_R (mag)	Type (days)	Status (old)
V194	10.8698	41.1379	18.86	17.84	0.14		
V195	10.8701	41.2739	20.43	19.80	0.87		
V196	10.8716	41.2094	20.83	19.67	0.66	P(90)	
V197	10.8743	41.1072	21.02	19.80	0.61	P(251)	
V198	10.8755	41.1717	20.82	19.48	0.68		
V199	10.8747	41.2306	20.96	20.39	0.55		
V200	10.8754	41.2677	20.18	19.29	0.70	P(135)	
V201	10.8758	41.2087	20.10	19.25	0.64	P(229)	
V202	10.8763	41.2762	19.75	18.76	0.49	P(565)	
V203	10.8784	41.1761	19.38	17.64	0.60		
V204	10.8785	41.2003	20.17	19.00	0.65		WR
V205	10.8783	41.2071	21.00	20.10	0.75		
V206	10.8780	41.2246	20.87	19.26	0.66		
V207	10.8794	41.0988	20.59	19.45	0.73	P(209)	
V208	10.8786	41.1859	20.43	19.72	0.60	P(125)	
V209	10.8790	41.2090	20.25	19.27	0.88		
V210	10.8812	41.2769	20.84	20.04	0.79		
V211	10.8815	41.0666	21.66	20.67	0.96		
V212	10.8822	41.2039	18.68	17.38	0.28		V
V213	10.8821	41.2133	20.79	19.73	1.00		
V214	10.8817	41.2857	20.23	19.11	0.49		
V215	10.8830	41.0475	20.95	19.93	2.54		
V216	10.8831	41.1957	19.49	17.58	1.01		
V217	10.8829	41.2261	20.52	18.98	0.69		
V218	10.8835	41.2643	20.30	19.66	0.41		
V219	10.8837	41.1973	19.93	19.66	0.50		
V220	10.8837	41.2464	20.27	19.54	0.66	P(129)	
V221	10.8864	41.2054	18.47	17.73	0.10		
V222	10.8860	41.2096	20.95	19.98	0.94	P(237)	
V223	10.8872	41.2187	19.48	19.19	0.26		
V224	10.8880	41.2028	16.70	16.82	0.69	No	Em0
V225	10.8889	41.0919	20.76	19.78	0.60		
V226	10.8888	41.1270	21.02	19.90	0.67		
V227	10.8887	41.1609	19.72	19.24	0.37		
V228	10.8886	41.2593	20.03	19.14	0.47		
V229	10.8902	41.1980	20.48	20.06	0.40	P(10)	V
V230	10.8904	41.2065	21.11	20.49	0.85		
V231	10.8918	41.1353	21.08	20.00	0.83		
V232	10.8916	41.1526	18.87	18.17	1.71		
V233	10.8915	41.1810	21.10	19.64	1.23	P(87)	
V234	10.8921	41.2012	20.58	19.75	0.76	P(130)	
V235	10.8947	41.2186	20.40	19.69	0.36		
V236	10.8969	41.1890	20.73	19.57	0.46	P(281)	
V237	10.9000	41.0936	21.37	20.56	1.30	P(111)	
V238	10.9001	41.1833	20.61	19.52	0.47		
V239	10.9012	41.1684	19.17	18.24	0.33	P(267)	
V240	10.9006	41.2437	20.18	19.13	0.75	P(200)	
V241	10.9029	41.1049	20.50	19.57	0.33		
V242	10.9037	41.0863	20.89	20.16	0.83		
V243	10.9049	41.0891	20.02	18.96	0.27		
V244	10.9062	41.0915	21.67	20.55	1.27	P(92)	
V245	10.9065	41.1976	20.43	19.50	0.33		
V246	10.9069	41.0425	20.45	19.62	0.52	P(76)	
V247	10.9072	41.1781	18.96	17.96	0.18		No
V248	10.9066	41.2136	20.95	19.56	0.57	P(161)	
V249	10.9086	41.2285	20.94	20.19	0.81		
V250	10.9089	41.2563	20.27	19.15	0.90		
V251	10.9098	41.0580	20.69	19.86	1.13	P(159)	
V252	10.9097	41.2373	21.02	19.70	0.87		
V253	10.9115	41.2791	20.84	20.70	0.61		
V254	10.9122	41.2087	19.04	17.87	0.44		
V255	10.9116	41.2197	21.00	19.69	1.01		
V256	10.9123	41.2700	20.33	19.33	0.51	P(127)	
V257	10.9132	41.1772	19.56	18.08	0.63		
V258	10.9127	41.2278	20.03	19.56	0.38		
V259	10.9132	41.2318	20.69	19.83	0.76		
V260	10.9132	41.2382	20.92	19.86	0.78		
V261	10.9128	41.2494	20.53	19.50	0.79	P(261)	
V262	10.9147	41.1574	21.67	20.69	0.93		
V263	10.9155	41.1633	20.25	20.12	0.49		
V264	10.9148	41.1788	19.92	19.02	0.39	P(202)	
V265	10.9162	41.2199	21.56	20.56	0.88	P(90)	
V266	10.9160	41.2613	21.56	20.28	1.04	P(93)	
V267	10.9156	41.2625	21.09	20.09	0.61	P(282)	
V268	10.9168	41.2607	20.88	19.81	0.86	P(237)	
V269	10.9178	41.0693	21.59	20.49	1.29		
V270	10.9179	41.0720	20.58	19.77	0.79	P(146)	
V271	10.9182	41.1991	18.89	17.49	0.32		
V272	10.9188	41.1912	20.58	19.36	0.65		
V273	10.9225	41.2038	19.75	18.17	0.71		
V274	10.9220	41.2165	20.34	19.71	0.52	P(289)	
V275	10.9225	41.1284	21.07	19.80	0.97	P(204)	
V276	10.9235	41.2064	20.47	20.00	0.44	P(289)	
V277	10.9226	41.2564	19.86	19.13	0.35		V
V278	10.9237	41.1579	20.57	19.23	0.56	P(260)	
V279	10.9253	41.2452	19.87	19.65	0.34		
V280	10.9263	41.1486	20.65	19.71	0.95	P(220)	
V281	10.9271	41.0825	21.30	20.32	1.22	P(130)	
V282	10.9272	41.2404	21.03	19.94	1.02		
V283	10.9279	41.2180	20.07	19.70	0.42	P(143)	
V284	10.9283	41.2451	18.19	16.96	0.16		Em0
V285	10.9302	41.1418	21.11	19.47	0.76	BI 215	
V286	10.9331	41.1736	19.52	18.30	0.18		
V287	10.9339	41.1519	20.86	20.07	1.00	P(167)	
V288	10.9354	41.1634	20.22	19.96	0.43		
V289	10.9352	41.2619	20.69	19.38	0.69		
V290	10.9358	41.1583	19.23	17.91	0.21	P(226)	
V291	10.9363	41.2569	20.54	19.42	0.49		
V292	10.9373	41.2573	20.73	19.53	0.73		
V293	10.9380	41.1878	19.36	17.90	0.36		
V294	10.9381	41.2078	19.12	17.85	0.36	P(283)	
V295	10.9394	41.1564	20.07	19.17	0.35		As
V296	10.9395	41.1898	20.53	20.32	0.38	P(151)	
V297	10.9401	41.1918	19.79	18.34	0.27		
V298	10.9400	41.1990	20.84	20.02	0.54		
V299	10.9397	41.2250	20.64	19.63	0.61	P(135)	
V300	10.9423	41.1941	18.29	16.71	0.56		
V301	10.9421	41.1968	19.44	17.89	0.23		V
V302	10.9430	41.1858	18.83	17.66	0.25	P(278)	
V303	10.9425	41.2541	17.75	16.49	0.31		V
V304	10.9441	41.1398	20.68	18.99	0.38	P(151)	
V305	10.9448	41.1580	20.91	20.64	0.51		Em0
V306	10.9454	41.2125	20.50	18.06	0.56		
V307	10.9465	41.2238	21.18	20.18	1.04		
V308	10.9473	41.2010	18.13	16.70	0.27		
V309	10.9483	41.1746	18.56	17.29	0.40		
V310	10.9479	41.2158	20.63	19.22	0.79		
V311	10.9496	41.1004	21.64	21.06	1.10	P(124)	
V312	10.9514	41.0777	21.35	20.16	1.33		
V313	10.9535	41.1131	21.45	20.44	1.03		
V314	10.9529	41.1693	20.93	19.77	0.45	P(255)	
V315	10.9544	41.2239	19.74	18.46	0.22		
V316	10.9548	41.1911	20.16	19.26	0.45	P(139)	LeV
V317	10.9561	41.2117	20.00	18.67	0.30		V
V318	10.9570	41.1137	21.30	20.25	1.20		
V319	10.9580	41.0875	21.15	20.15	1.01		
V320	10.9579	41.2191	20.91	19.83	0.80		
V321	10.9590	41.2077	20.66	19.90	0.54	P(275)	
V322	10.9596	41.1620	20.68	19.94	0.46		
V323	10.9631	41.1822	20.46	19.61	0.40	P(269)	
V324	10.9633	41.1915	20.87	19.76	0.96		
V325	10.9628	41.2046	19.44	18.19	0.34		
V326	10.9645	41.1564	21.41	19.94	0.88	P(238)	
V327	10.9652	41.1953	20.87	19.68	1.37		
V328	10.9659	41.1552	20.77	20.49	0.53		
V329	10.9660	41.1759	21.38	19.88	1.02		Em0
V330	10.9684	41.1714	18.77	17.75	0.34		
V331	10.9680	41.1863	21.22	20.07	0.84	P(252)	
V332	10.9722	41.1565	20.26	20.24	0.26		
V333	10.9729	41.2215	19.56	18.53	0.35		
V334	10.9751	41.2155	18.47	17.14	0.45		
V335	10.9773	41.1857	18.87	17.41	0.29		
V336	10.9771	41.2285	21.16	20.20	0.84	P(139)	
V337	10.9792	41.2059	20.98	20.08	0.95		
V338	10.9803	41.1827	21.83	20.70	1.02		
V339	10.9804	41.2149	18.71	17.45	0.34	P(194)	
V340	10.9820	41.1503	20.92	19.75	1.05		
V341	10.9833	41.1240	20.98	20.39	0.96	P(108)	
V342	10.9829	41.2225	20.47	19.83	0.54		
V343	10.9845	41.2029	19.56	18.46	0.19		Em0
V344	10.9871	41.2284	20.06	19.93	0.38		
V345	10.9884	41.1936	18.55	16.90	0.33		V
V346	10.9898	41.2233	20.53	19.27	0.86		Em0
V347	10.9923	41.2092	20.34	19.27	0.43	P(160)	
V348	10.9925	41.1644	20.45	19.53	0.52	P(118)	
V349	10.9927	41.2138	20.66	20.39	0.61		
V350	10.9939	41.1377	21.48	19.99	0.89		
V351	10.9980	41.1466	21.48	20.31	1.02		
V352	11.0013	41.2092	21.34	20.19	0.71		
V353	11.0131	41.1880	19.75	18.98	0.47		
V354	11.0140	41.1548	20.61	19.81	1.30	P(204)	
V355	11.0162	41.2050	20.25	19.22	0.60		
V356	11.0168	41.1422	20.97	20.16	0.89		
V357	11.0197	41.1600	20.39	19.13	0.97		
V358	11.0278	41.1894	19.50	19.26	0.22	P(132)	
V359	11.0288	41.2008	20.70	19.53	0.67		
V360	11.0304	41.1756	20.90	19.96	1.45		

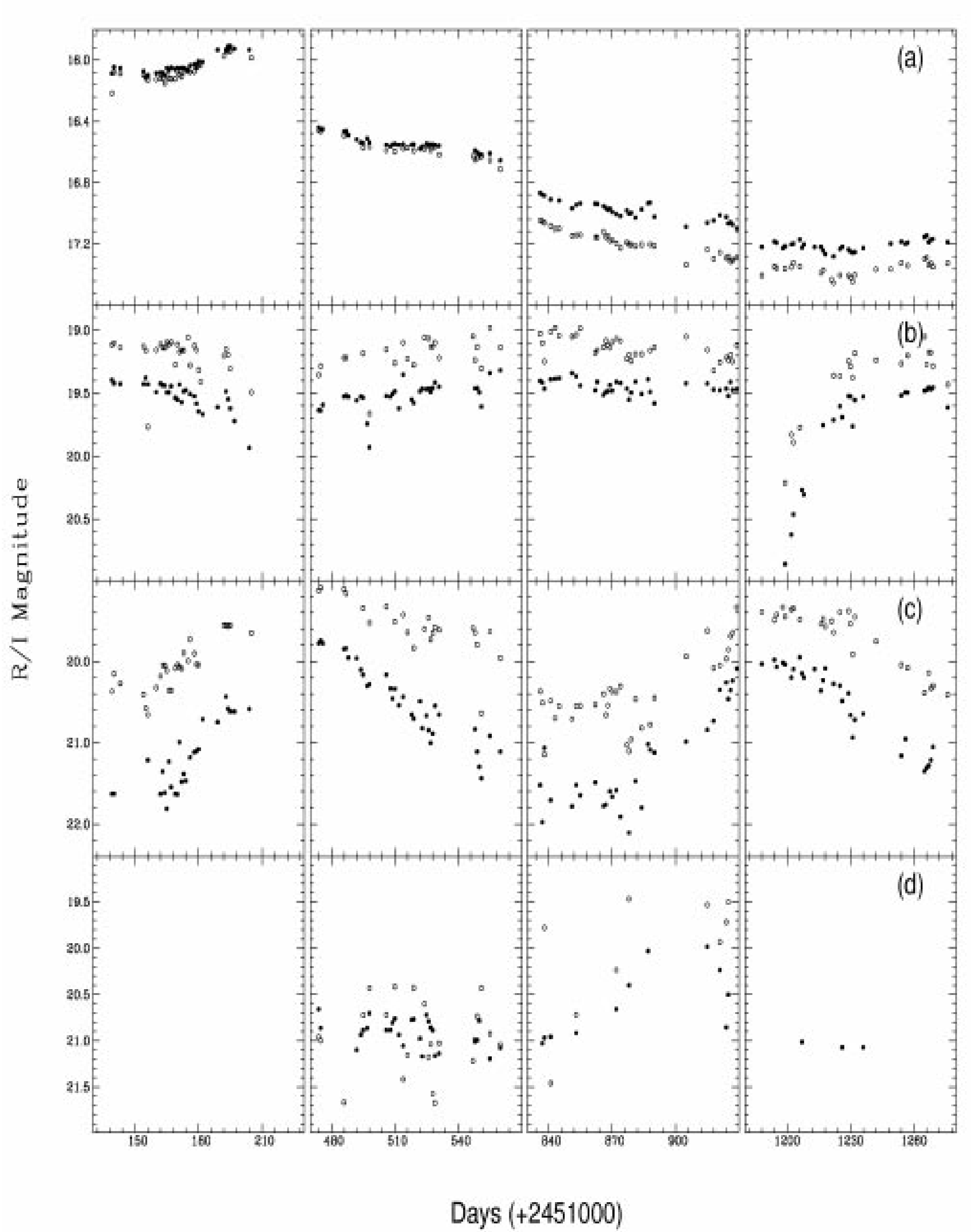

Fig. 9. The typical light curve of 4 other varaibles (for further detail see Sect. 6). Filled and open circles represent R and I filters respectively